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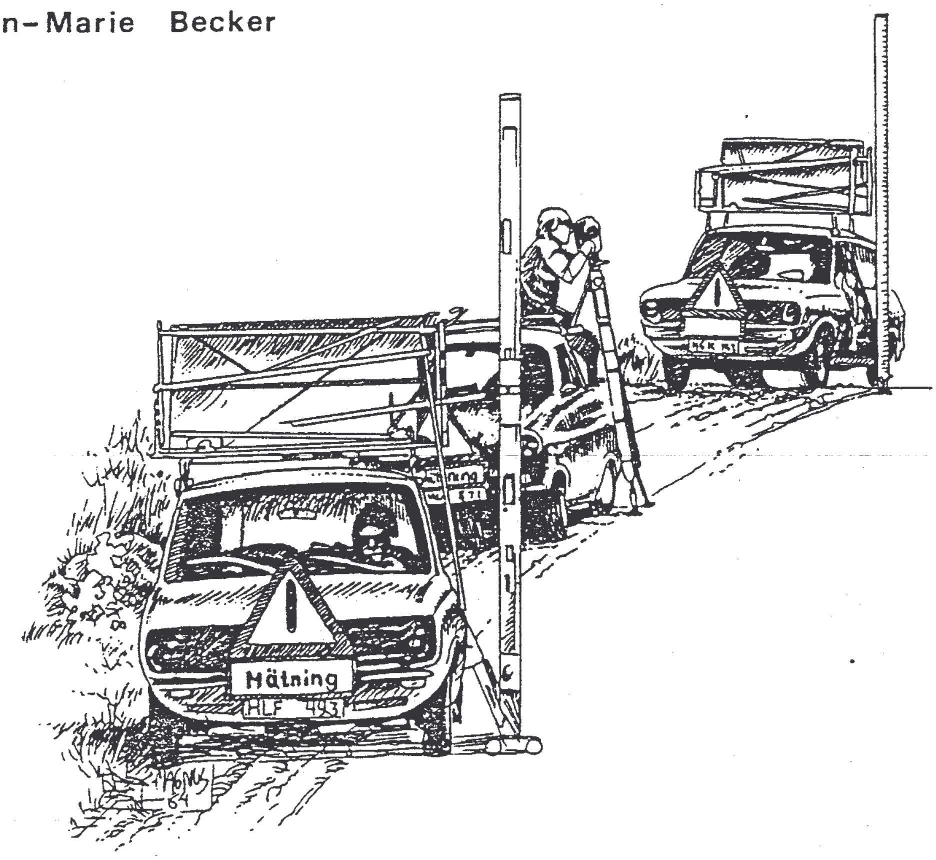

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1 INTRODUCTION

At the National Land Survey of Sweden a great deal of attention is paid to studying ways and methods to rationalize geodetic activities.

An example of the result of the rationalization process is the development of rapid, efficient and accurate methods for triangulation and trilateration using laser Geodimeters and light-weight portable towers. Using these methods the whole of the Swedish network has been remeasured. The on-going third national precise levelling programme is been carried using a fully automated system built up around motorized levelling techniques and a fully computerised handling of data from the field to the archives. The programme was initiated in 1974 and has been continually updated to keep abreast of modern technological developments.

Our experiences of modern levelling techniques is based on the levelling of over 37 000 km carried out under a wide variety of physical conditions, and with a large number of different field crews working with types of equipment.

The results can be summarised as follows:

- a daily production of 12 km for a 5,5 hr working day;
- a relevelling rate which is less than 5 %;
- a field season from spring to autumn with a standard i.e. without stops in the middle of the day.

Currently tests are in progress which hopefully will result in the development of new methods for trigonometric heighting and traversing.

This report will deal with motorized levelling and, thereafter, the development of new techniques.

2 THE SWEDISH MOTORIZED LEVELLING TECHNIQUE (ML)

With the fully motorized levelling technique, all work is performed directly from the vehicles. The operators do not leave their seats. The only exception to this rule is when connecting to bench marks.

The complete motorization of levelling techniques was made possible by the development of the specially designed Zeiss Jena Ni002 reversible compensator level; but also required modification of vehicles and the construction of special accessories.

This technique has been described in several publications (Becker 1977, 1984...) therefore only mention will be made of the essential characteristics.

2.1 Equipment and personnel

A motorized levelling party consists of four persons: (two surveyors acting alternatively as observer and driver-booker and two staff men) and three vehicles (one vehicle carrying the instrument and two vehicles carrying the staffs).

The three vehicles are equipped with:
- a precision electronic trip meter, Digitrip;
- a programmed data log Micronic 445;
- a set of warning signs;
- some spare parts.

The specially constructed accessories and modifications on the vehicle carrying the instrument are:
- hole in the rear-platform for the legs of the tripod (set-up without contact with the vehicle);
- a lifting device to raise and lower the tripod and instrument;
- a removable linen roof for protection against wind, rain and sun;
- a radio communication system (interphone);
- a special tripod with long adjustable legs and special feet;
- a quick-setting mounting device for the instrument;
- an additional tripod of the standard type;
- an electric thermometer for the registration of air t^{o};
- a desk;
- a printer coupled to the Micronic for the simultaneous print-out of all data (doubling and control).

The vehicles carrying the staffs are specially equipped with:
- a specially modified door to facilitate manipulation of the levelling staff;
- a mounting system allowing movement of the staff during set-up and transport;
- a special, heavy base plate;
- a (3,5 m long) precise levelling staff with an invar inset with double graduations in centimeters starting at 0,5 m;
- a centring arrangement on the base of the staff;
- three bull's eye levels with viewing mirrors;
- electronic sensors coupled to the invar band for recording the band temperature;
- an additional staff for the difficult connections;
- classical foot plates, iron pins.

The ZEISS JENA Ni002 level is a high precision automatic level, specially designed for motorized levelling. Thanks to innovations in its design, this instrument has played a decisive roll in the full motorization of levelling. The elbow-joint eyepiece permits pointing of the instrument and the observation of fore- and backsights from one fixed observing position. Moreover, the reversible pendulum eliminates the problems related to the necessity of having equal fore- and backsights (difficult to achieve with vehicles).

2.2 The work method

All operations are performed from the vehicles. For this reason working methods have been designed to minimize observing time and optimize the quality of the results.

To conciliate both aims, the following routines have been adopted:

- the movement of the vehicles always occurs in the same chronological order;
- the Ni002 is set up according to the principle of the "red trousers" method;
- the observations are carried out as follows (1) to (6).

Position I, left scale				
backsight	Stadia hair (1)	- centre hair	(2)	
foresight	" " (3)	" "	(4)	
Position II, right scale				
foresight		" "	(5)	
backsight		" "	(6)	

As a rule, the forward and reverse levellings are executed at different times (day, hour) under different meteorological conditions and by different observers.

All instruments are checked once a week. Staffs are calibrated at least twice a year (every graduation on the invarband) with laser interferometer komparator.

2.3 The observations and their registration

The data are collected simultaneously in the three vehicles, according to a fixed schedule, preprogrammed in the data logs. Recording routines are not the same for instrument and staff vehicles.

During the registration process, simple computations and checks against given tolerances are done automatically in the data log. The information stored in the data stacks is transferred on to magnetic tapes for transfer into the data bank.

3 RESULTS

To better illustrate the results obtained using motorized levelling techniques a comparison with standard techniques is made below. The following criteria have been chosen for the comparative study: efficiency quality and working conditions.

3.1 Efficiency

The efficiency of a levelling technique can be illustrated on the one hand by the average (daily or hourly) production and total season production, and on the other hand by the cost per levelled kilometer.

TABLE 1 LEVELLING STATISTICS FOR PERIOD 820501 TO 821027

PARTY	KM TOTAL	KM CHECK	KM REPAY	EFF HRS	NO. BMs	NO. SET-UPS	SET-UPS PR.HR	DIFFERENT BM TYPE BM	BM	BM	BM	AVSIGHT LGTH	AV. LGTH	KM PR.HR	NO. WORK DAYS
1	1,293.6	0.0	18.7	586.4	1387	16004	27.3	1307	12	10	47	40.4	932,7	2,21	100
2	1,101.3	216.3	0.0	589.9	1183	16496	28.0	1104	35	68	22	33,4	930,9	1,87	112
3	1,493.6	5.6	12.1	603.2	1623	18551	30.8	1304	91	67	90	40,3	920,3	2,48	112
4	1,358.7	33.4	27.0	622.2	1599	17217	27.7	1169	94	73	115	39,5	849,7	2,18	109
5	1,328.1	169.8	0.0	572.4	1400	17990	31.4	1140	165	45	50	36,9	948,6	2,32	107
	=======	=====	====	======	====	======	====	====	===	===	===	====	=====	====	===
	6,575.3	425.1	57,8	2974.1	7192	86,258	29.0	6024	397	263	324	38,1	916,4	2,21	540

TABLE 2 PRODUCTION STATISTICS FOR PERIOD 1976–1984 WITH MOTORIZED LEVELLING

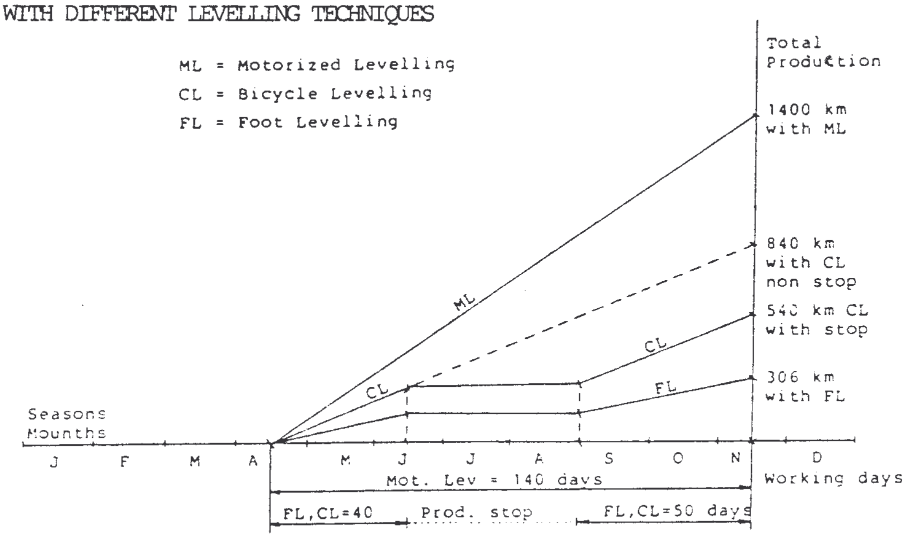
YEAR	NUMBERS OF PARTY	FIELD WORK DAYS	TOTAL PRODUCTION IN KM			DAILY PRODUCTION KM			RELEVELLING
			ACCEPTED	RELEVELLED	TOTAL	ACCEPTED	RELEVELLED	TOTAL	%
1976-1981	1-5	2 023	18 374	1 186	19 560	9,1	0,6	9,7	6,0
1982-1984*	4-6	1 520	17 420	759	18 179	11,5	0,5	12,0	4,2
Total	-	3 362	33 900	1 945	35 845	10,1	0,6	10,7	5,2

*) Measurement with 3,5 m invarstaff.

Table 1 and Table 2 shows the results obtained in Sweden:

- We can see that the average hourly production rate for a motorized levelling party is about 2,2 km;
- The average daily production rate under the last 3 years (when using 3,5 m invarstaff) is about 12,0 km;
- The effective working time during a normal 8 hours day is only on an average about 5,5 hours;
- The total time needed to perform all operations at one set-up of the instrument, including transport time, is on an average between 1,6 to 2,4 minutes;
- In Scandinavian countries our experience shows that it is possible to use motorized levelling without interruption during the whole field season: for Sweden this is about 140 days. In the same period the foot (FL) and bicycle (CL) levelling techniques can only be used during 90 days (spring and autumn). Moreover, using standard methods special precautions must be taken and the observations must be interrupted in the middle of the day due to shimmer, refraction etc.

Figure 1 PRODUCTION DURING FIELD SEASON WITH DIFFERENT LEVELLING TECHNIQUES



- Figure 1 shows that with (ML) motorized levelling technique the total production per season is increased by at least a factor of 2,5 compared to (CL) bicycle levelling and a factor 4 for (FL) foot levelling.

When analysing the cost for a levelled kilometer, it is significant that in the industrialized countries, and especially in Sweden, the part representing the wages is relatively high being about 90 %. Capital costs (for equipment and cars) are less than 7 % of the total cost. To reduce costs, it is therefore important to reduce the number of operators to a minimum while maintaining on optimal production rate. ML requires only 4 persons while FL and CL require 4 to 5 and even more persons.

In comparative study we have as a principle only dealt with the factors related to production in the field. A better comparison is obtained if data processing and works which follows the field work are also included. The Swedish system is fully computerized from data collection in the field (Micronic) through processing (computer PR1ME), to the storage and output of the results (height data bank).

3.2 Quality of the results: accuracy

In order to be able to correctly judge of the quality of the results, we should keep in mind the conditions (regulations and tolerances) which have steered the execution of the field work.

The permitted difference between the forward and reverse levelling of a line is $2\sqrt{L}$ mm/km (L = distance in km) for the first order network.

Field work is in progress during the whole season without interruption under the most varying working conditions and by a variety of staff.

The average percentage of relevelling for all levelling carried out up to the present time with motorized techniques is 5,2 % (see table 2).

In his studies and analysis of our results from the period 1977-78 (Remmer 1979) notes that:

- the optimal non-acceptance limit is about $2{,}3\sqrt{L}$ mm/km between a forward and reverse levelling;
- in this case, the number of undetected gross errors only amounts to 2 o/oo.

However, the best criterion to judge of the quality of the measurements is the mean error per kilometer, which can be calculated either from the circuit closures, or from the deviations of the runs. In both cases we note that the mean errors remain under ± 1 mm/km, which complies with the norms for precise levelling.

It is worth mentioning here some of the factors which make these results possible with motorized techniques. Among these we can note:

- a higher speed of operation: reduction of the settlement and heaving effects linked to the time factor (staff, tripod);
- a higher line of sight: the instrument is more than 2 m above the ground: almost total elimination of the refraction effects and of shimmer effects;
- perfect stability of the staffs under all operating time;
- permanent check of verticality with the help of the 3 bull's eye levels;
- greater stability of the foot plates;
- no movement around the tripod: sinking effect reduced;
- greater stability of the tripod thanks to the modified feet;
- less fatigue because of the regular change of observers;
- fore- and back sights always over the same surfaces (forewards and backwards) = identical symmetrical refraction.

3.3 The working conditions

The introduction of motorized techniques has greatly improved the field working environment since nearly all operations are performed from the vehicles. The purely physical part of levelling has been considerably lightened:

- no more long and tiring walks with heavy and cumbersome equipment;
- no need to manually hold the staffs in a vertical position;
- work in seated position for the staff men and the booker;
- special desk faciliting the booker's work;
- preprogrammed automatic registration with the help of the Micronic data logs;
- protection against rain, wind etc.

The weight, volume and quantity of the equipment used need not be limited. Currently, working conditions are such that nearly half of the personnel is female. Safety has been strongly improved because of the numerous warning signs and signals which are mounted on the vehicles. Road users have more respect for the levelling parties. No incident has occurred in the ten past years.

3.4 Conclusions

The Swedish experience with motorized levelling (more than 37 000 km) has confirmed that this technique, at the moment, is the most appropriate one for large scale precise levelling work.

The obtained results are:
- average daily production about 12 km (by only 5,5 working hours);
- cost per levelled km reduced by about 50 %;
- uninterrupted working throughout the season and during normal working hours;
- improved working environment;
- accuracy as good or even higher as with classical methods even under unfavourable conditions;
- several countries have successfully adopted the Swedish motorized levelling; system (Danmark, Holland, Norway, France, USA, Zambia a s o).

4 NEW TECHNIQUES AND TESTS

During the coming field season experimental work will be carried out to test a number of new techniques. Some of this work will be concerned with the evaluation of methods which have already been introducted in other countries; other parts will be related to the further development of these techniques.

Of particular interest are: indirect levelling and motorized traversing to determine X, Y and Z coordinates.

4.1 Double Motorized Levelling (DML)

This technique is based on the use of only two vehicles as opposed to the now well-known three vehicle technique. DML can be used for simultaneous single levelling. The two vehicle are identically equipped and are basically the same as the instrument vehicle used for the classical motorized levelling (ML) with the exception of the levelling staff which is mounted on both vehicles on a support close to the instrument so that it can be manipulated by the observer.

Each car is crewed by two surveyors with the combined roles of driver, booker, observer and staffman. Each vehicle is equipped with short-wave radio equipment for inter-car communication and booking is done with the help of electronic data logs. In addition to base plates and temperature recording equipment, a third staff is carried for making connections to bench marks.

FIGURE 2 : DOUBLE MOTORIZED LEVELLING

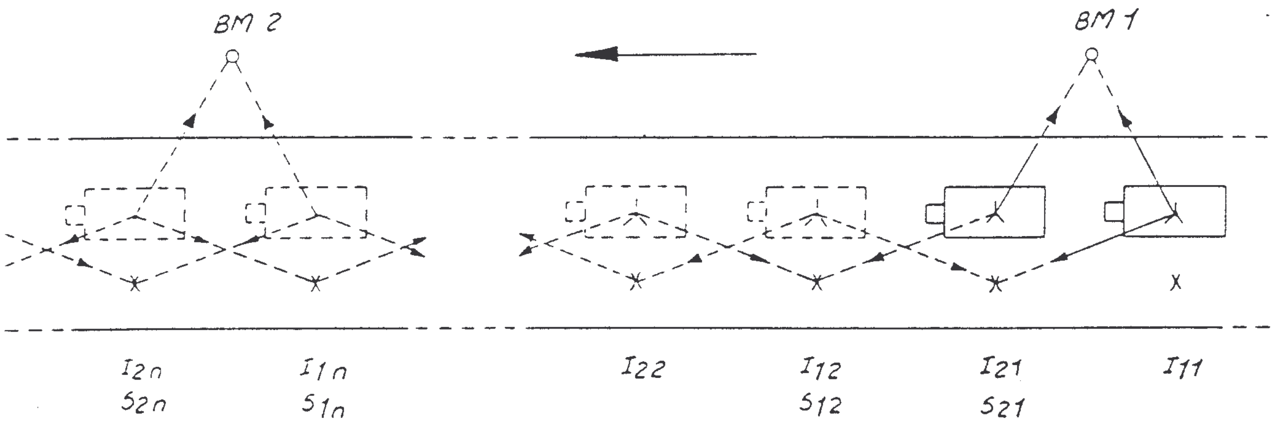


Figure 2 illustrates a possible measuring routine. Each observer records his observations in his own data log. A run between two bench marks results in two independent height determinations measured simultaneously and in the same direction.

The use of this technique appears to offer a number of advantages since investment costs will be reduced by about 20%. Increase in productivity has been estimated to about 15%.

This technique will result in sets of reciprocal observations at the same time: in addition to losing the Δh check, the observations are correlated both in time and with respect to environmental conditions. The overall simplicity of this technique make further investigations interesting. Of particular interest will be the accuracy which can be attained.

4.2 Trigonometric Levelling (TL)

In the early 1970's a number of experiments were carried in the north of Sweden using this technique, transporting crews and equipment by both car and helicopter. Distances were measured using an AGA model 6 Geodimeter and angles observed reciprocally with standard second order theodolites. A modified version of height traversing was also used in the national retriangulation programme.

The results achieved in broken mountainous terrain were very promising. Using the method along roads did not result in any significant improvements when compared with "cycle" levelling which was the method in use at that time for second order levelling. In the mountains it was possible to produce results with an accuracy of 10 mm.

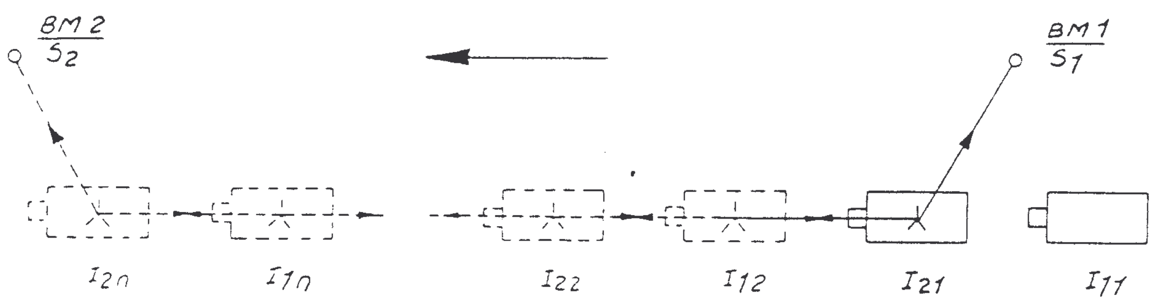
The new generation of total stations has made it possible to develop new and improved methods. In 1981 Bahnert in East Germany reported results of the order of ± 4 mm/km.

4.21 Motorized Trigonometric Levelling (MTL)

In the USA (Whalen 1984), France (Kasser 1984) and in Canada very promising results have been reported using this technique. The technique has been well documented and is based on the use of total stations to carry out reciprocal observations.

To speed up and improve accuracy, the total stations will be equipped with a specially designed adapter on which both a reflector and target can be fitted. All observations will be recorded using data logs and will be checked and provisionally computed during the actual field operations.

FIGURE 3: MOTORIZED TRIGONOMETRIC LEVELLING (MTL)



The tests will be begun using two vehicles and, thereafter, a series of tests using three vehicles will also be carried out. With three vehicles we feel that productivity will be significantly increased and observing times will be decreased which should improve accuracy.

4.22 Double Motorized Trigonometric Levelling (DMTL)

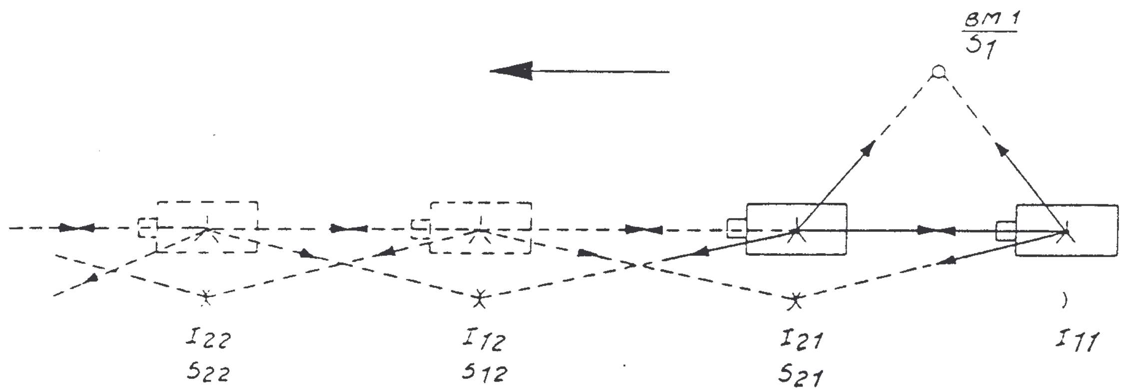
We plan to study the feasibility of combining both methods 4.1 and 4.21. The same vehicles as will be used for DML will also be used for this series of tests. The Ni002 instruments will be replaced with total stations (AGA 142, Kern a s o). On the eccentrically mounted levelling staves a twin set of reflectors and targets will be mounted to form a fixed base on the staves with a centre point approximately 2,5 m above ground level.

A proposed measuring routine is as follows:

- a set of reciprocal distance and vertical angle observations will be observed as for MTL followed by observations to the targets and reflectors which are mounted on the levelling staves.

Measurements will be done according to the leap-frog method, see figure 4. Connections will be made to bench marks using a third staff.

FIGURE 4 : THE DOUBLE MOTORIZED TRIGONOMETRIC LEVELLING (DMTL)



The combined results will give four separate height traverses i.e. two reciprocally observed height traverses instrument to instrument and two separate traverses instrument to staff.

Possible advantages of this method are:

- improved accuracy from the combined technique;
- decrease of refractive effects: reciprocal observations;
- increased speed: long lines of sight simultaneous forward and reverse observations;
- better productivity in hilly areas;
- lower production costs.

Foreseeable disadvantages are:

- high capital costs: total stations;
- longer set-up times;
- need for better planning and reconnuissance;
- connections two bench marks can be time-consuming;
- data capture routines must be very care-full defined.

It is possible to operate using 3 vehicles but the logistics of the operations would be relatively complicated and disadvantages will presumably outweigh the advantages of such a configuration: handling the observation data would be particularly complicated.

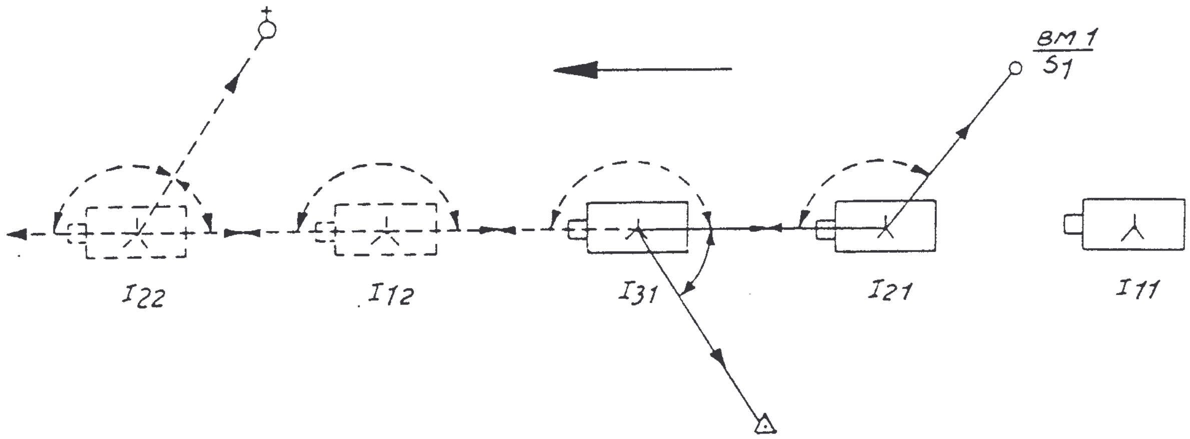
4.3 The Motorized XYZ Technique (MXYZ)

National networks normally comprise separate layouts for the height and planimetric nets each with its own demarcation system. Field observations are carried out as completely separate activities, often by separate sections within the organisation. There is a need for coordinate information for the computation and documentation of height networks. The increasing interest for digital mapping techniques is a further argument for an XYZ determination of bench marks.

The method described in section 4.2 can possibly be adapted to make it possible also to determine station coordinates. Tests will be carried out to test this concept.

It is planned to use three vehicles, each with a total station on which a reflector and target is mounted. Connections to bench marks will be made using the same type of staff as will be used for MTL. The staves will be fitted with a specially constructed centring arrangement to make possible an exact set-up both over bench-marks and traverse and triangulation points. The observation programme will be the following (see figure 5).

FIGURE 5: THE MOTORIZED XYZ TECHNIQUE (MXYZ)



The instrument vehicle I11 starts from the bench mark BM1 on which the staff S1 is placed.
1. Determination of height difference: I21-BM1
2. Horizontal angle: BM1-I21-I31

The instrument vehicle I1 moves from I11 to I12.

3. Determination of height difference: I21-I31
4. Horizontal angle: I21-I31-I12

The instrument vehicle I2 moves from I21 to I22.

5. Determination of height difference......

Connections to coordinated points will be made as soon as visibility permits the observation of directions and/or distances. The type and number of connections will depend on accuracy requirements.

The opinion at the National Land Survey of Sweden is that this method has considerable potential for second and third order networks both in Sweden and in developing countries. Particular attention will be concentrated on accuracy and economy.

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